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DESIGN OF LARGE TRUSSED RIBS

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DESIGN OF LARGE TRUSSED RIBS.

The development of large bombers and passenger airplanes brings up the problem of the design of large ribs of adequate strength and minimum weight. Experience has proven that the ply-wood type of construction with web cut-outs is uneconomical for large ribs. The use of a trussed-web construction may be made economical and it is the purpose of this report to describe satisfactory methods of design. To illustrate the application of the principles of design, an example is worked out in detail in the Appendix. The example chosen is the design of a duralumin trussed rib for a 4,760-pound corps observation airplane.

LOAD DISTRIBUTION ALONG THE CHORD.

Ribs should be designed for two conditions of loading corresponding to different angles of attack of the wings.

The first condition of loading considered is a triangular distribution with the apex 25 to 33 per cent of the chord to the rear of the leading edge of the wing. The positions of the centers of pressure for these distributions are 41.6 and 44.5 per cent, respectively, from the leading edge. The location of the apex of the triangular loading diagram within the limits designated is chiefly a matter of judgment. Experience has shown that the lower chord member in the second panel to the rear of the front spar is the limiting chord member, and that the section is determined by the direct stress and bending moment just to the left of the second panel point from the front spar. The apex of the triangular loading diagram should be located close to this panel point in order to secure a maximum value of the combined stresses. The center of pressure for high speed is farther back than this, but the loading stated gives the most severe stresses in the limiting compression chord member, and when combined with a load factor slightly in excess of that for low incidence will prove the limiting case for the web members. This condition of loading will be referred to as Case A.

The second condition of loading to be investigated is for high incidence, and will be referred to as Case B. From a study of the load distribution along the chord for various airfoils it was found that the curve representing the variation in this loading could be closely approximated by a parabola. Figure 1 shows a typical pressure distribution curve for high incidence, and the parabolic curve assumed to represent it. Figure 2 gives the location of the vertex of the parabola in terms of the wing chord for various positions of the center of pressure. The position of the center of pressure for high incidence for a given wing is that at which the center of pressure reaches its most forward position except for wings in which K_y becomes a maximum before the center of pressure reaches that position. In the latter case the position of the center of pressure corresponding to maximum K_y is used. The construction of

the curve shown in Figure 2 is taken up in detail in the Appendix.

The third condition of loading is that due to the initial tension in the fabric due to the action of the dope. The stresses in the members of the rib due to high incidence and low incidence loadings are superimposed upon the stresses due to fabric tension. The stresses due to fabric tension are considered by applying two equal and opposite thrusts with the same line of action, the point of application of one being at the leading edge and of the other at the trailing edge of the wing. The magnitude of each thrust is equal to the rib spacing in inches multiplied by twice the fabric tension per linear inch measured parallel to the direction of the spars. A value of 3 to 4 pounds per linear inch for fabric is recommended in Pippard and Pritchard's "Aeroplane Structures." The Materials Section at McCook Field have conducted experiments which indicate that the average value of this stress is 2 to 2½ pounds per linear inch with a maximum of 5 pounds per linear inch. Four pounds per linear inch represents a conservative design value for the fabric tension.

DISTRIBUTION OF LOAD BETWEEN FLANGES OF RIB.

The distribution of the load between the flanges of the rib is dependent upon the manner in which the fabric is attached to the ribs. Two cases should be considered: (1) In which the upper surface of the fabric is attached directly to the upper flange and in which the lower surface of the fabric is attached to the lower flange, and (2) in which the lacing cords pass around both flanges of the rib. In the first case the upper flange of the rib will receive about 70 per cent of the total load, and the lower flange will receive the remainder. In the second case the entire load will be transmitted to the lower flange. The distribution of the load between the flanges has an important influence on the design of the flange members, but a negligible effect on the design of the web members.

LOAD FACTORS.

The load factor for the ribs should be slightly in excess of the load factor for the rest of the wing structure in accordance with the well-established principle of structures that the subordinate parts of a structure should be stronger than the main parts. For high incidence and low incidence loading the load factors should be about one-half a factor greater than the corresponding load factors for the wing structure. Case A loading is intermediate between the low and high incidence condition and a reasonable load factor for the wing structure would be a mean between the load factors for the two types of loading.

No load factor should be applied to the stresses produced by fabric tension, due to the fact that the strains in the

fabric in the longitudinal direction of an airplane's axis does not increase materially in flight since the fabric is attached all along the ribs.

RIB SPACING.

The spacing of ribs is taken up fully in the "Structural Analysis and Design of Airplanes," page 118, and in Pippard and Pritchard's "Aeroplane Structures," pages 189 and 190. The article referred to states that rib spacing is a function of wing loading and maximum speed, and that rib spacing for large airplanes is limited by fabric strength rather than rib design. For large bombers, corps observation airplanes, and large passenger airplanes the minimum rib spacing outside of the slip stream should be about 15 inches. Within the slip stream of the propeller the spacing should be reduced to approximately 70 per cent of the normal spacing to take into consideration the increased lift due to the slip stream effect.

The application of a method to serve as a guide in the determination of the maximum rib spacing is taken up in detail in the Appendix.

TYPES OF RIB TRUSS.

Howe: Diagonal web members in compression. Vertical web members in tension.

Pratt: Diagonal web members in tension. Vertical web members in compression.

Warren: Web members alternately tension and compression.

Subdivided Warren: Diagonal and vertical web members alternately tension and compression.

For thin wing sections like the USA-5 and RAF-15 it is advisable to use the Warren truss for economy of material.

For thick wing sections like the USA-27 there is no appreciable advantage in strength between the Howe, Pratt, and subdivided Warren types of truss. The subdivided Warren or Howe truss in which the diagonal web members adjacent to the spars are in compression is recommended in general, however, because of the increased rigidity of the connection between the rib and spar made possible. In general it is much better to have a thrust exerted by the rib against the spar than a pull, and this is effected by the use of a Howe or subdivided Warren truss.

The Pratt type of truss has an application in metal construction in which the two diagonal members adjacent to each spar are continuous. The diagonals may be flattened out under the spars and riveted to the bottom flanges of the spar, thus securing a rigid connection.

DETERMINATION OF STRESSES IN MEMBERS.

The first step in determining the direct stresses in the members of the rib truss is to obtain the panel concentrations for the high and low incidence loadings. These are obtained from the curves of loading by assuming that the sections of the chord between panel points are simple beams. The load at each panel point would then be approximately equal to the area under the loading curve bounded by ordinates half way to the adjacent panel points. Seventy per cent of the load should be considered acting at the upper panel point and 30 per cent

at the lower panel point, and this distribution of the load would apply to the reactions as well. The direct stresses will not be effected seriously if the entire load is assumed to act at the upper surface. A diagonal should be assumed in place of each spar to secure continuity of truss action, and one-half of the load should be applied at the panel points adjacent to the imaginary diagonal member. Once the panel concentrations have been determined and the thrust due to fabric tension ascertained, it is simply a question of making a graphical determination of the direct stresses considering the rib a pin-jointed structure.

The bending moments in the chord members due to the distributed load are calculated by considering the chord a straight beam continuous over panel points between spars. The distribution of the load between the chords for different methods of attaching the fabric to the ribs has been taken up on page 1.

The bending moments in the chord members due to initial eccentricities caused by the curved outline of the rib may be safely ignored.

DESIGN OF WEB MEMBERS.

The design of web members may be classified under two heads, (1) those which are symmetrical about an axis in the plane of the truss, and (2) those which are unsymmetrical about that axis.

(1) The web members should be designed for the limiting stress in high incidence, low incidence, or reversed flight. The stresses are reversed in reversed flight, and their magnitude may be taken as 50 per cent of the stresses in high incidence. This assumption is based on the fact that the center of pressure is well forward in reversed flight, and that the relation between the load factors for reversed flight and high incidence is somewhat less than 50 per cent.

The column formula recommended for the design of the compression web members are the Johnson parabolic column formula and the Euler column formula within their ranges. The Johnson formula ceases to be effective when the allowable unit stress falls below 50 per cent of the yield point of the material in compression. Below that value the Euler column formula should be used.

The Johnson formula is as follows:

$$\frac{P}{A} = f - \frac{f^2}{4c\pi^2 E} \left(\frac{L}{\rho} \right)^2$$

f = yield point of material.

c = a constant depending on the fixity of the ends of the column.

The remainder of the terms have their ordinary significance.

The Euler column formula is as follows:

$$\frac{P}{A} = \frac{c\pi^2 E}{(L/\rho)^2}$$

c = a constant with same values as in the parabolic formula.

The fixity coefficients for the compression web members of reinforced ply-wood truss ribs have been found in test to be conservatively represented by the following values: 1.25 in a plane normal to the rib, and 2 in the plane of the rib. For steel web members riveted to the flanges of the rib, it is recommended that a fixity coefficient of one

should be used in both planes. In the Appendix there are several combined parabolic and Euler column curves for spruce, duralumin, and mild steel. Figures 3 and 4.

When reinforced ply-wood truss ribs are used, the design of the web members is based on the following considerations:

(a) Sufficient gluing surface at the extremities of each web member between the ply wood and the reinforcing strip to develop the reinforcing strip before the ply-wood gusset narrows down to the width calculated for column strength.

(b) Sufficient sectional area to develop the tensile or compressive stress. Figure 5 has been reproduced from a report of the Haskelite Research Laboratory, and gives the allowable tensile and compressive resistance of various ply woods when the applied load makes different angles with the direction of the face grains.

In riveted metal construction there must be sufficient net sectional area at the extremities of compression members so that the yield point of the material for compression members or the tensile strength of the material for tension members will not be exceeded. The allowable bearing values of rivets of various diameters on duralumin and steel plate and the shearing values of one-eighth-inch rivets of steel and duralumin are tabulated in Tables IV and V of the Appendix.

(2) When the web members are unsymmetrical about an axis in the plane of the truss, the design of the web members is somewhat different. An example is found in reinforced ply-wood truss rib construction in which reinforcing is used on only one side of the web. The stress is applied to the web members through strips through the glued surfaces. Due to the lack of symmetry of the web members about an axis in the plane of the rib, the stress is applied eccentrically, causing bending stresses in the compression members. A method of analysis of columns subjected to combined bending and direct stresses, known as the method of secondary deflections, has given excellent results and is strongly recommended for the design of compression web members of an unsymmetrical section as stated. To illustrate its use an example will be worked out in detail. The example chosen is the design of a vertical web member for a 15-foot 0-inch reinforced ply-wood truss rib.

Stress = -223 pounds.

Length = 18.85 inches.

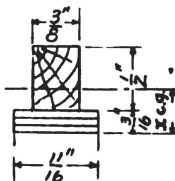
Effectiveness of ply wood referred to spruce = 0.435.

Effective area = 0.2436 square inch.

$X_{c.g.} = 0.358$ inch.

$I_{c.g.} = 0.00926$ inch.⁴

$r = 0.195$.



The primary eccentricity is equal to the sum of the initial eccentricity in the member and the deflection due to the load. The former term is equal to the distance from the center line of the ply wood to the center of gravity of the section, while the latter term is equal to the deflection at the center of a beam subjected to terminal couples.

$$\text{Primary deflection} = \left(X_{c.g.} \cdot \frac{3}{32} \right) + \frac{ML^2}{8EI} = (0.358 - 0.094) + \frac{223 \times 0.264 \times 18.85}{8 \times 1,600,000 \times 0.00926} = 0.440 \text{ inch.}$$

Primary bending moment = $223 \times 0.440 = 98.2$ inch-pounds.

The next step is to determine the uniform load which will produce the same bending moment at the center of a beam freely supported at the ends.

$$98.2 = \frac{wL^2}{8}; w = 2.21 \text{ pounds per linear inch.}$$

Deflection due to uniform load

$$= \frac{5}{384} \frac{wL^4}{EI} = \frac{5}{384} \times \frac{2.21 \times 18.85^4}{1,600,000 \times 0.00926} = 0.246 \text{ inch.}$$

Ratio between secondary and primary eccentricities

$$= \frac{0.246}{0.440} = 0.558$$

The total bending moment is the sum of a series which may be determined as follows:

$$M = \frac{M_{\text{primary}}}{1 - 0.558} = \frac{98.2}{0.442} = 223 \text{ inch-pound.}$$

$$f_c = \text{fiber stress in direct compression} = \frac{223}{0.2436} = 920 \text{ pounds/square inch.}$$

$$f_b = \text{fiber stress in bending (compression fibers)} = \frac{223 \times 0.358}{0.00926} = 8,625 \text{ pounds/square inch.}$$

$$f_{\text{allowable}} = \frac{f_b}{f_b + f_c} (F - C) + C = \frac{8,625}{9,545} (10,300 - 2,200) + 2,200 = 9,525 \text{ pounds per square inch.}$$

The web members of the rib cited were designed throughout in accordance with this principle, and failure occurred in one of the web members when the applied test load was 4 per cent in excess of the designed load.

DESIGN OF CHORD MEMBERS.

The chord members are subjected to direct stresses due to truss action, and bending stresses due to beam action. The deflections between panel points due to the distributed load, and the initial eccentricities in the chords between panel points due to the wing section may be ignored. The fixity coefficient of the chord members in the plane of the rib may be taken as 2. In considering the strength of the chord at a panel point, column action should be allowed for by assuming that the chord is a column with a length equal to 25 per cent of the sum of the lengths of the adjacent panels. When reinforced ply-wood truss ribs are designed the actual section at a panel point including the gusset should be used in connection with the peak bending moment due to the distributed load. In such designs it is also advisable to investigate the stresses at a point on either side of the panel point where the normal section begins.

The allowable stresses due to combined bending and direct stresses are found by the following formula:

$$f_a = \frac{f_b}{f_b + f_c} (F - C) + C$$

f_a = maximum allowable combined fiber stress.

f_b = fiber stress in bending.

f_c = fiber stress in direct compression.

F = modulus of rupture material.

C = allowable fiber stress for column action alone.

In riveted metal construction the question arises as to the relative advantages of using (1) the same rivet for attaching two adjacent web members to the flanges or (2) of using a separate rivet for the attachment of each member.

The former method is especially adapted to tubular web member construction in which the web members may be slit back at each end along two diametrically opposite elements parallel to the axis of the tube. The flattened portions at the ends of each tube should grip the vertical webs of the flanges on each side and should be caught by the same rivet. To avoid eccentricities, the rivet hole should be located as near the center of gravity of the flange as possible.

For economy of production and structural reasons it is recommended that a separate attachment to the flanges should be used for the web members in construction in which these members are of a channel section. The intersection of the lines of action of the stresses in the web members at each panel point should be close to the center of gravity of the flanges in order to avoid serious eccentricities.

The relative advantages of the split versus the routed cap strip and the approved methods of connecting the ribs to the spars in wooden construction are considered fully in the "Structural Analysis and Design of Airplanes." The trend of present rib design is to use the routed cap strip and a tenoned web for the transfer of the shear to the spar. The split cap strip is preferable to the routed cap strip when the web of the rib is very thin because of the danger in the latter case of splitting the web by nailing. The use of steel clips to attach the cap strip to the spar has been discontinued.

In metal construction U-shaped and channel-shaped flanges have been found to be satisfactory. In duralumin the radius of curvature should not be less than four times the thickness of the metal.

The connection between the rib and spar may be constructed very rigidly in metal. In the Appendix, figures 6 and 7, are given details of the connection of a duralumin rib to a wooden spar, and the connection of a duralumin rib of a different construction to a metal spar. The use of metal ribs and wooden spars is not desirable in general, but in this particular case it was necessary to develop sufficient strength in the rib of the lower wing adjacent to the fuselage of the Martin bomber when subjected to stresses caused by the discharge of the 75 mm. cannon.

The complete design of a trussed metal rib is carried through in the Appendix.

COMPRESSION RIBS.

Compression ribs are subjected to vertical lift loads, and also to thrusts due to their action as struts in the drag truss. The portion of the compression ribs beyond the spars should be designed for the same stresses as occur in the other ribs. The portion between spars should be designed for combined vertical loads equal to those which the other ribs are subjected to, and also for the compression in the drag truss. The following procedure is recommended for the design of trussed compression ribs.

1. Apply two equal and opposite thrusts of unity in the plane of the drag truss to the ribs. The points of application of the forces are at the spars.
2. Distribute the loads of unity to the flanges in the inverse relation of their vertical distances from the flanges.

3. Solve the stresses in the portion of the rib between spars for the thrust.

4. Multiply the stress due to a unit thrust by the actual compression in the compression rib and combine these stresses with the stresses due to the vertical lift loads.

5. Design the compression rib for the combined stresses. In addition the compression ribs stabilize the spars against twisting, but these stresses are indeterminate.

TYPES OF COMPRESSION RIBS.

In wood the double-web, cruciform, and box spar construction with the same profile as the other ribs have application. The double-web type may be designed as recommended above. The other two types should be designed as laterally loaded columns with an unsupported length equal to the distance between spars. The direct stress would be equal to the compression from the drag truss and the lateral load would be equal to the distributed load (Case A).

In metal construction it would in most cases be advisable to use the same form of construction as the spars.

FALSE (NOSE) RIBS.

False ribs should be used between main ribs from the leading edge to the front spar. The main function of these ribs is to maintain the correct airfoil section. The members of the false rib should be of the same size as the corresponding members of the main ribs, and should have a rigid connection to the spar. "The use of thin veneer or ply wood on the upper wing surface between the leading edge and the front spar, and preferably extending the entire length of the wing, is almost essential on airplanes of a speed greater than 120 miles per hour. For lower speed airplanes only the slip-stream length need be covered. Mahogany ply wood three sixty-fourths inch thick has proved very satisfactory for this purpose. When no such reinforcing is used the rib spacing should be somewhat closer than when the recommended reinforcing is present."

Special reference should be made to Air Service Information Circular, Vol. 3, No. 212, entitled "Experimental Reinforced Plywood Truss Ribs." This report is a summary of the Forest Products Laboratory's work on the design of ribs with a 15-foot chord for the Navy Department, and includes the following types of construction:

1. Wrapped veneer strap.
2. Twisted veneer strap.
3. Navy design.
4. Pratt truss with individual web members.
5. Double Pratt truss with individual web members, and the Warren truss with individual web members.

This report also states what has been accomplished with the Barling, Handley-Page, and Glenn Martin ribs. The most important part of the report states the development which has been made in the design of reinforced ply-wood truss ribs, and the superiority of this construction over all other types of wood construction so far developed.

References.—Structural Analysis and Design of Airplanes, Engineering Division, Air Service, Aeroplane Structures, A. J. Pippard and J. L. Pritchard.

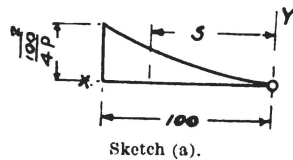
¹ From Structural Analysis and Design of Airplanes.

APPENDIX.

CONSTRUCTION OF FIGURE 2.

Figure 2 gives the location of the vertex of a parabola representing the variation in pressure along a wing chord in high incidence for various positions of the center of pressure ranging from 0.250 to 0.340 of the wing chord. The curve is determined as follows:

First consider the case in which the vertex of the parabola is at the trailing edge. See sketch (a).



Determine s =distance to center of gravity of the area under the parabola

$$s = \frac{\int x dm}{\int dm} \text{ where } dm = K dx dy \quad K \text{ assumed } = 1$$

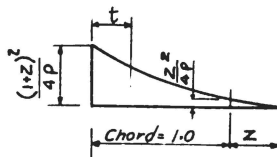
$$s = \frac{\int_0^{100} \int_0^{x^2} 4P x dx dy}{\int_0^{100} \int_0^{x^2} 4P dx dy} \text{ as the equation of the parabola is } x^2 = 4Py$$

$s = 75$

Determine A =area under the parabola.

$$A = \int dm = \int_0^{100} \int_0^{x^2} 4P dx dy = \frac{x^2}{4P} \times \frac{x}{3}$$

Next consider the case in which the vertex of the parabola is in the rear of the trailing edge.



Let t =distance to center of gravity of area under the parabola and limited by ordinates at the leading and trailing edges.

$$t = \frac{\frac{(1+Z)}{3} \frac{(1+Z)^3}{4P} \times 0.25 - \frac{Z}{3} \times \frac{Z^2}{4P} \frac{(4+Z)}{4}}{\frac{(1+Z)}{3} \frac{(1+Z)^2}{4P} - \frac{Z}{3} \times \frac{Z^2}{4P}}$$

$$t = \frac{6Z^2 + 4Z + 1}{4(3Z^2 + 3Z + 1)}$$

The curve shown in figure 2 is the graphical representation of the equation within the extreme limits of the position of the center of pressure in high incidence.

DETERMINATION OF RIB SPACING.

Application of a method to determine maximum rib spacing. From British Report 1912-1913 No. 84, reviewed in McCook Field Report, R. D. M. No. 277.

Let t =stress per foot length in the transverse fiber.

P =pressure per unit area on fabric.

D =distance between ribs in feet.

e =strain in fibers due to fabric bulging between the ribs under the pressure.

$$t = PD \sqrt{\frac{1}{24e}}$$

The problem is then to obtain a value of " t " at which the strain in the filler of the fabric determined from the formula is equal to the strain secured from the stress-strain diagram of a test specimen of the fabric.

For example, assume the following conditions:

Load factor in high incidence for wing=6.5.

Load factor in high incidence for fabric=19.5.

Normal wing loading in pounds per square foot=10.

Wing load with load factor of 19.5=195 pounds per square foot.

Spacing of ribs=30 inches.

' Mercerized cotton airplane fabric (grade B) Spec. No. 16005-A.

The load factor for the fabric should be three times the load factor for the wing structure, since the local stresses in the fabric at a high angle of incidence corresponding to that occurring in flattening out after a dive have been shown to be about three times the average load. The severest stresses occur in a fabric under this condition.

$$t = 195 \times \frac{30}{12} \sqrt{\frac{1}{24e}} = \frac{98.6}{\sqrt{e}}$$

$$t^2 = \frac{9940}{e} \text{ or } e = \frac{9940}{t^2}$$

t	120 lbs./ft.	240 lbs./ft.	360 lbs./ft.	480 lbs./ft.	
e	0.0287	0.0334	0.0383	0.0435	From stress-strain diagram for filler.
e	.690	.172	.0767	.0432	From formula $e = \frac{9940}{t^2}$

The specifications call for 875 pounds per foot of width for this fabric, so that theoretically the fabric is almost twice as strong as necessary. The effect of tears and defects introduce stresses which it is impossible to calculate, and as a result this method of analysis of fabric stresses should be used merely as a guide.

TYPICAL DESIGN OF RIB.

To illustrate the application of the principles of rib design, the complete design of the ribs for the CO-2 corps observation airplane will be worked out.

DESIGN DATA.

Type: Biplane.

Gross weight including supercharger=4,760 pounds.

Weight of wind structure assumed=540 pounds, corresponding to 1.15 pounds per square foot.

Area upper wing=262.5 square feet.

Area lower wing=206.5 square feet.

Total area=469 square feet.

Chord=75 inches.

Wing section: U. S. A. 27.

Spar location:

Front spar $8\frac{1}{2}$ inches from leading edge.

Rear spar $51\frac{1}{2}$ inches from leading edge.

Load factors for wing structure: High incidence=6.5; low incidence=4.5; reversed flight=3.0.

HIGH INCIDENCE.

Area of upper wing=262.5 square feet.

Effective area lower wing= $0.90 \times 206.5 = 185.9$ square feet.

Effective area wings=448.4 square feet.

Unit load on upper wing= $\frac{4760}{448.4} = 10.62$ pounds per square foot gross.

Unit load on lower wing= $0.90 \times 10.62 = 9.56$ pounds per square foot gross.

Net unit load on upper wing= $10.62 - 1.15 = 9.47$ pounds per square foot.

Net unit load on lower wing= $9.56 - 1.15 = 8.41$ pounds per square foot.

Center of pressure location at 0.274 chord.

Load factor for ribs= $6.5 + 0.5 = 7.0$.

LOW INCIDENCE.

Area of upper wing=262.5 square feet.

Effective area of lower wing= $0.95 \times 206.5 = 196$ square feet.

Effective area of wings=458.5 square feet.

Unit load on upper wing= $\frac{4760}{458.5} = 10.37$ pounds per square foot gross.

Unit load on lower wing= $0.95 \times 10.37 = 9.86$ pounds per square foot gross.

Net unit load on upper wing= $10.37 - 1.15 = 9.22$ pounds per square foot.

Net unit load on lower wing= $9.86 - 1.15 = 8.71$ pounds per square foot.

The rib spacing outside of the slip stream is taken as 15 inches and within the slip stream as 9 inches.

RIB LOADING.

(a) High incidence: Load per rib= $\frac{75}{12} \times \frac{15}{12} \times 9.47 \times 7 = 517$ pounds.

(b) Case A loading (see pp. 1 and 2): Load per rib= $\frac{75}{12} \times \frac{15}{12} \times 9.22 \times 6 = 432$ pounds.

The load factor for Case A is the average between the load factors for high and low incidence plus one-half of a load factor.

DISTRIBUTION OF LOAD BETWEEN SPARS.

High incidence:

Front spar $\frac{(51.75 - 20.75)}{43.5} \times 517 = 367$

Rear spar..... = 150

517

Case A loading:

Front spar $\frac{(51.75 - 33.40)}{43.5} \times 432 = 182$

Rear spar..... = 250

432

LOAD DISTRIBUTION ALONG THE CHORD.

High incidence:

From figure 2 for c. p.=0.274; Z=0.10 chord=7.5 inches.

Area under parabola= $\frac{1}{3} \times 82.5 \times \frac{(82.5)^2}{4P} - \frac{1}{3} \times 7.5$

$\times \frac{7.5^2}{4P} = 517$ pounds P=90.6.

Equation of parabola of loading= $x^2 = 4 \times 90.6y$.

Ordinate at leading edge= $\frac{82.5^2}{4 \times 90.6} = 18.8$ pounds.

Ordinate and trailing edge= $\frac{7.5^2}{4 \times 90.6} = 0.155$ pounds.

CASE A LOADING.

$\frac{1}{2} \times 75 \times X = 432$

X=11.5 pounds.

The apex of the triangular loading is assumed to be one-third the chord from the leading edge, which corresponds to a center of pressure of 0.445 chord.

FABRIC TENSION.

The fabric tension is assumed to be 4 pounds per linear inch measured parallel to the direction of the spars.

Thrust= $2 \times 15 \times 4 = 120$ pounds.

GENERAL DESCRIPTION OF RIBS.

Material: Duralumin.

Chord members: U-shaped.

Web members: Sheet duralumin bent to tubular shape except at ends, where they are slit back and riveted to flanges.

Diagonals adjacent to spars are continuous.

Type of truss: Pratt. See diagrammatic sketch, figure 8.

Single-riveted construction.

Table I gives the panel concentrations for the three loading conditions. Refer to figure 8.

TABLE I.

Panel point.	Panel concentration.		
	High incidence.	Case A.	Fabric tension. ¹
a.....	28.0	0.56	Pounds. 120
b.....	62.3	5.62	
c.....	47.3	9.47	
d.....	69.8	25.5	
e.....	98.0	67.9	
f.....	76.4	95.95	
g.....	55.0	79.2	
h.....	35.0	58.2	
i.....	16.1	28.0	
j.....	9.6	19.5	
k.....	10.5	20.8	
l.....	7.3	18.0	
m.....	1.7	3.60	120
Total.....	517.0	432.0	

¹ The loads due to fabric tension are applied at the leading and trailing edge; and are applied along the line connecting these points.

The stresses were solved graphically with the results shown in Table II.

TABLE II.—Tabulation of direct stresses.

Chord.			Web.		
Member.	High incidence. ¹	Case A.	Member.	High incidence. ¹	Case A.
		Pounds.			Pounds.
B-1.....	- 70	- 35	1-2	+ 22	+ 22
C-3.....	-103	- 23	2-3	+ 62	- 5
E-6.....	- 70	+ 4	6-7	+262	+220
F-8.....	+118	+161	7-8	- 75	-108
G-10.....	+205	+261	8-9	+115	+137
H-13.....		+137	9-10	- 15	- 43
I-15.....		- 62	10-11		- 14
K-18.....		- 89	11-12		- 38
L-20.....		- 51	12-13		+153
M-22.....		- 32	13-14		-110
N-22.....		- 73	14-15		+264
O-21.....		- 73	18-19		+ 45
P-19.....		- 54	19-20		- 18
R-14.....		-240	20-21		+ 23
S-12.....	-318	-354	21-22		- 4
T-11.....	-318	-353			
U-9.....	-324	-365			
V-7.....	-240	-263			
X-2.....	- 71	- 80			
Y-1.....	- 76	- 83			

¹ The stress diagram for the high incidence condition was discontinued at a point at which the high incidence loading no longer limited the design.

BENDING MOMENTS IN CHORDS.

Case A loading gives the most severe bending stresses in the chord members between spars. The analysis was first made on the assumption that the entire load was carried by the lower chord. Figure 9 is the bending moment diagram for the lower chord. To provide for the contingency of the attachment of the fabric to the upper chord, and also to provide for the bending stresses in the upper chord due to reverse flight, the upper chord should be designed for about 70 per cent of the bending moment in the lower chord.

DESIGN.

TYPICAL DESIGN OF WEB MEMBER.

Member 6-7:

Stress in direct flight, Case A loading=+220 pounds.

Stress in direct flight, high incidence loading=+262 pounds.

Stress in reversed flight loading=-131 pounds.

Length=11.7 inches.

Assume $\frac{3}{8}$ inch diameter by 0.014-inch gauge.

Area=0.01585 square inch.

$\rho=0.1282$.

$I/\rho=91.5$.

f allowable=11,700 pounds per square inch.

f actual= $\frac{131}{0.01585}=3,250$ pounds per square inch.

The designs of the web members are tabulated in Table III. A liberal margin of safety is allowed because the resistance of duralumin to fatigue has not been investigated thoroughly.

The horizontal rivet at the extremity of each web member should be designed like a bridge pin to resist shearing and bearing stresses. The rivet must have sufficient bearing on the vertical web of the flanges so that the allowable bearing value of the material will not be exceeded. Tables IV and V give the allowable values of one-sixteenth inch diameter, three thirty-seconds inch diameter, one-eighth inch diameter, five thirty-seconds inch diameter, and three-sixteenths inch diameter duralumin and soft-steel rivets in single and double shear. The allowable bearing values of these rivets on commercial plates are also given.

Sufficient provision should be made to transmit the shear to the spars. See figures 6 and 7.

TABLE III.—Design of web members.

Member.	Limiting stress.	Length (inches).	Area (inch). ²	I (inch). ⁴	ρ (inch).	$L/S\rho$	Actual stress.	Allowable stress.	Section.
1-2		4.1							Material duralumin.
2-3	{ +62 H. I. -31 R. F.	6.0							
6-7	{ +262 H. I. -131 R. F.	11.7	0.01585	0.000264	0.1282	91.5	8,250	11,700	$\frac{3}{8}$ -inch diameter by 0.014-inch gauge.
7-8	-108 A	7.9	.01310	.000146	.1057	74.5	8,250	16,800	$\frac{3}{8}$ -inch diameter by 0.014-inch gauge.
8-9	{ +137 A -58 R. F.	11.6	.01310	.000146	.1057	110	4,425	8,200	$\frac{3}{8}$ -inch diameter by 0.014 inch gauge.
9-10	-43 A	7.5	.01035	.0000725	.0837	89.5	4,150	12,200	$\frac{1}{2}$ -inch diameter by 0.014-inch gauge.
10-11	-14 A	11.4							$\frac{1}{2}$ -inch diameter by 0.014-inch gauge.
11-12	-38 A	7.1							$\frac{1}{2}$ -inch diameter by 0.014-inch gauge.
12-13	+153 A	11.1							$\frac{3}{8}$ -inch diameter by 0.014-inch gauge.
13-14	+153 A	6.6	.01310	.000146	.1057	62.5	8,400	19,800	$\frac{3}{8}$ -inch diameter by 0.014-inch gauge.
14-15	+264 A	10.2	{ .01585 .01235 }				21,400	55,000	$\frac{3}{8}$ -inch diameter by 0.014-inch gauge.
18-19	+45 A	7.4							$\frac{3}{8}$ -inch diameter by 0.014-inch gauge.
19-20	-18 A	4.4							$\frac{1}{2}$ -inch diameter by 0.014-inch gauge.
20-21	+23 A	6.0							$\frac{1}{2}$ -inch diameter by 0.014-inch gauge.
21-22	-4 A	3.1							$\frac{1}{2}$ -inch diameter by 0.014-inch gauge.

¹ Gross.² Net.

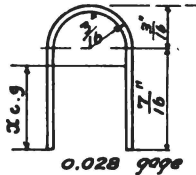
H. I.—high incidence loading.

R. F.—reversed flight loading.

A—Case A loading (intermediate between high and low incidence).

FLANGE DESIGN.

Member U-9 is the greatest stressed member of the lower chord, and the design of the member will be carried through.



Direct stress Case A loading = -365 pounds.
Bending moment center of panel = -25.4 inch pounds.
Bending moment at panel points = +53.9 inch pounds.
and +69.7 inch pounds.

$$\text{Properties of section} \begin{cases} \text{Gross area} = 0.0398 \text{ square inch.} \\ \text{Net area} = 0.0328 \text{ square inch.} \\ x_{c.g.} = 0.367 \text{ inch.} \\ I_{c.g.} = 0.00161 \text{ inch.}^4 \\ \rho = 0.201 \text{ inch.} \end{cases}$$

$$f_c = \frac{365}{0.0328} = 11,140 \text{ pounds per square inch.}$$

$$f_b = \frac{69.7 \times 0.367}{0.00161} = 15,850 \text{ pounds per square inch.}$$

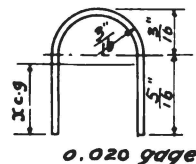
$$f_{\text{allowable}} = \frac{15,850}{26,990} (55,000 - 27,000) + 27,000 = 43,450 \text{ pounds per square inch.}$$

Member G-10 is the greatest stressed member in the upper chord.

Direct stress = +261 pounds Case A.

Bending moment center of panel = -27.1 inch pounds.

Bending moment at panel points = +48.8 or 40.6 inch pounds.



$$\text{Properties of section} \begin{cases} \text{Gross area} = 0.02365 \text{ square inch.} \\ \text{Net area} = 0.01865 \text{ square inch.} \\ x_{c.g.} = 0.2832 \text{ inch.} \\ I_{c.g.} = 0.000562 \text{ inch.}^4 \\ \rho = 0.154 \text{ inch.} \end{cases}$$

$$f_c = \frac{261}{0.01865} = 14,000 \text{ pounds per square inch.}$$

$$f_b = \frac{48.8 \times 0.2832}{0.000562} = 24,600 \text{ pounds per square inch.}$$

$$f_{\text{allowable}} = 55,000 \text{ pounds per square inch.}$$

The lower chord and upper chord were designed uniform throughout in order to simplify the construction.

STRENGTH-WEIGHT RATIO OF RIBS.

The strength-weight ratios of several wooden ribs are plotted against chord lengths in figure 10. It should be particularly noted that the strength in each case is the test load at failure for Case A loading, in which the center of pressure is from 41.6 to 44.5 per cent back from the leading edge. For a well-designed rib the strength-weight ratio will be considerably higher for high incidence loading.

The curve drawn indicates the efficiency that can be expected in the design of ribs of various chords. The curve is almost straight from 90 to 180. The decrease in the slope to the left of 90 is due to the fact that limiting sizes of web and chord members are reached below which it is undesirable to reduce the sections. With chord lengths under 100 inches it is difficult to attain as great an efficiency with metal ribs as with wooden ribs because the gauge of the metal is limited by local buckling stresses. For duralumin it is recommended that the minimum gauge for the upper chord should be 0.020, lower chord 0.028, and web members 0.014. When using channel or U-sections the ratio of the length of the unsupported outstanding leg to the thickness of the material should not exceed 16.

TABLE IV.—*Rivets—Shearing and bearing values based on ultimate stresses.*

[Values in pounds; dimensions in inches.]

	Shear.	Soft steel rivets and steel plate.					
		Rivet diameter	1/16	3/32	1/8	5/32	3/16
		Single shear per rivet	108	241	431	672	964
		Double shear per rivet	216	482	862	1,344	1,928
Bearing.	#24 B. W. G.	137	206	274	344	412	
	#22 B. W. G.	175	263	350	437	526	
	1/32	195	293	390	498	596	
	#20 B. W. G.	219	328	438	547	656	
	#18 B. W. G.	306	459	612	767	918	
	#16 B. W. G.	407	609	814	1,015	1,218	
	1/16 in.	390	586	780	976	1,172	
	3/32	587	878	1,174	1,460	1,756	
	1/8	780	1,172	1,560	1,952	2,344	

Based on steel:

Allowable shearing stress rivet steel=35,000 pounds per square inch.

Allowable bearing stress of steel plate=100,000 pounds per square inch.

TABLE V.—*Rivets—Shearing and bearing values based on ultimate stresses.*

[Values in pounds; dimensions in inches.]

	Shear.	Duralumin rivets and duralumin plate.					
		Rivet diameter	1/16	3/32	1/8	5/32	3/16
		Single shear per rivet	90	201	359	560	803
		Double shear per rivet	180	402	718	1,120	1,606
Bearing.	0.014	78	118	156	197	236	
	0.020	112	169	224	281	338	
	0.028	157	237	314	394	474	
	0.032	180	271	360	450	542	
	0.064	360	542	720	900	1,084	
	3/32	527	792	1,054	1,317	1,584	
	1/8	702	1,056	1,404	1,760	2,112	

Based on duralumin:

Allowable shearing stress=30,000 pounds per square inch.

Allowable bearing stress=90,000 pounds per square inch.

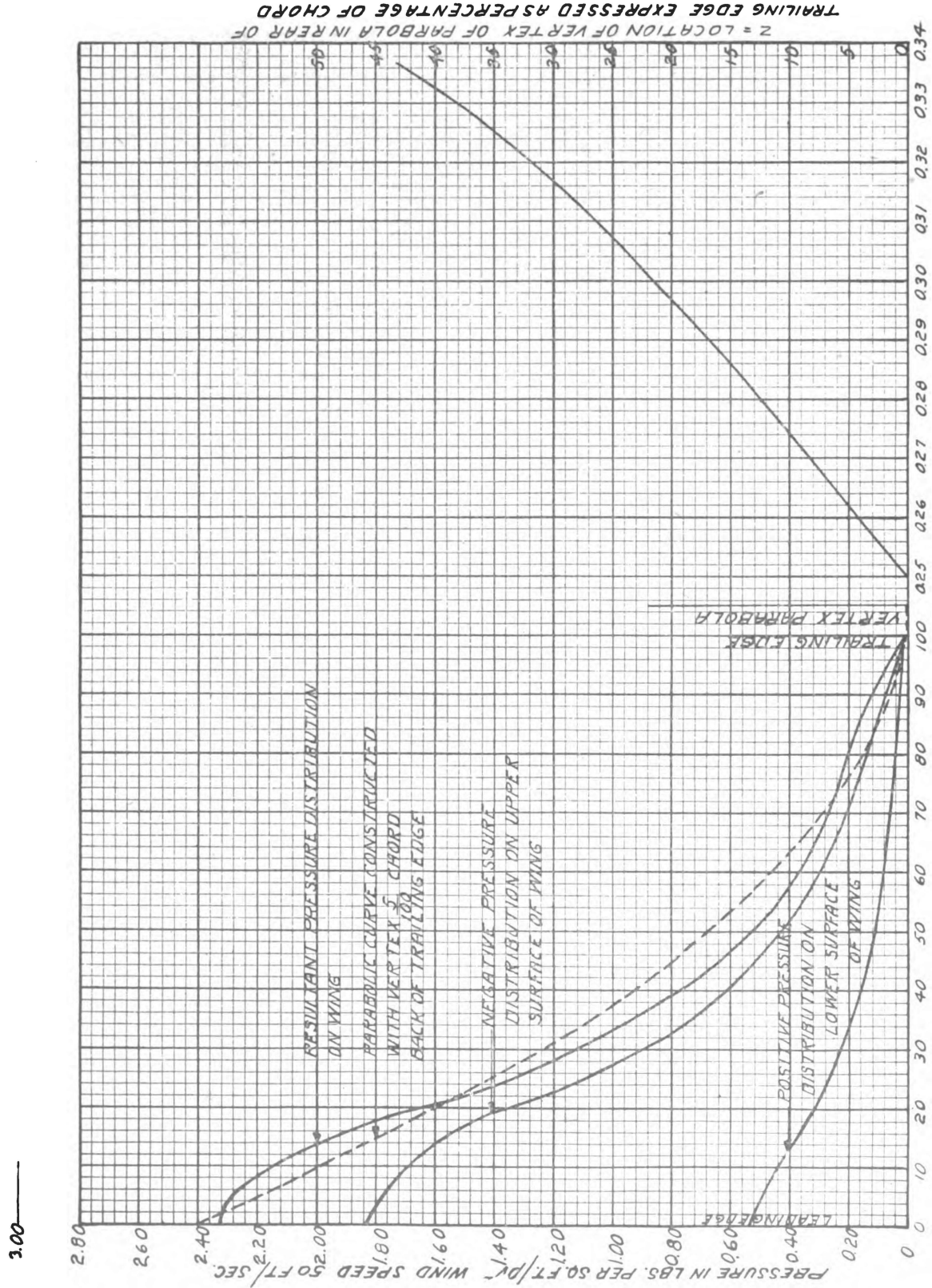


FIG. 1.—Per cent chord from leading edge.

FIG. 2.—Location of c. p. in rear of leading edge.

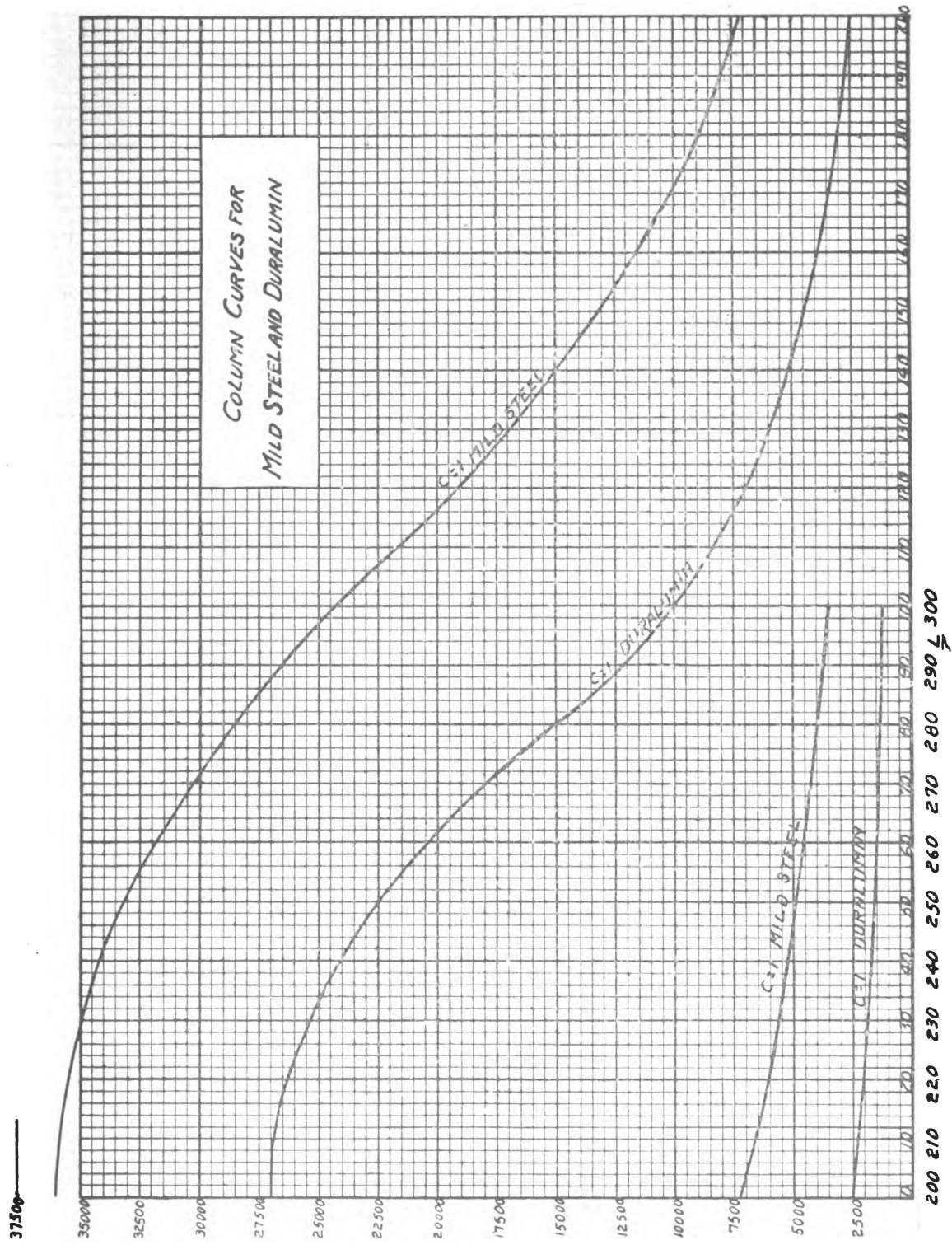


FIG. 3.—Allowable unit stress in compression.

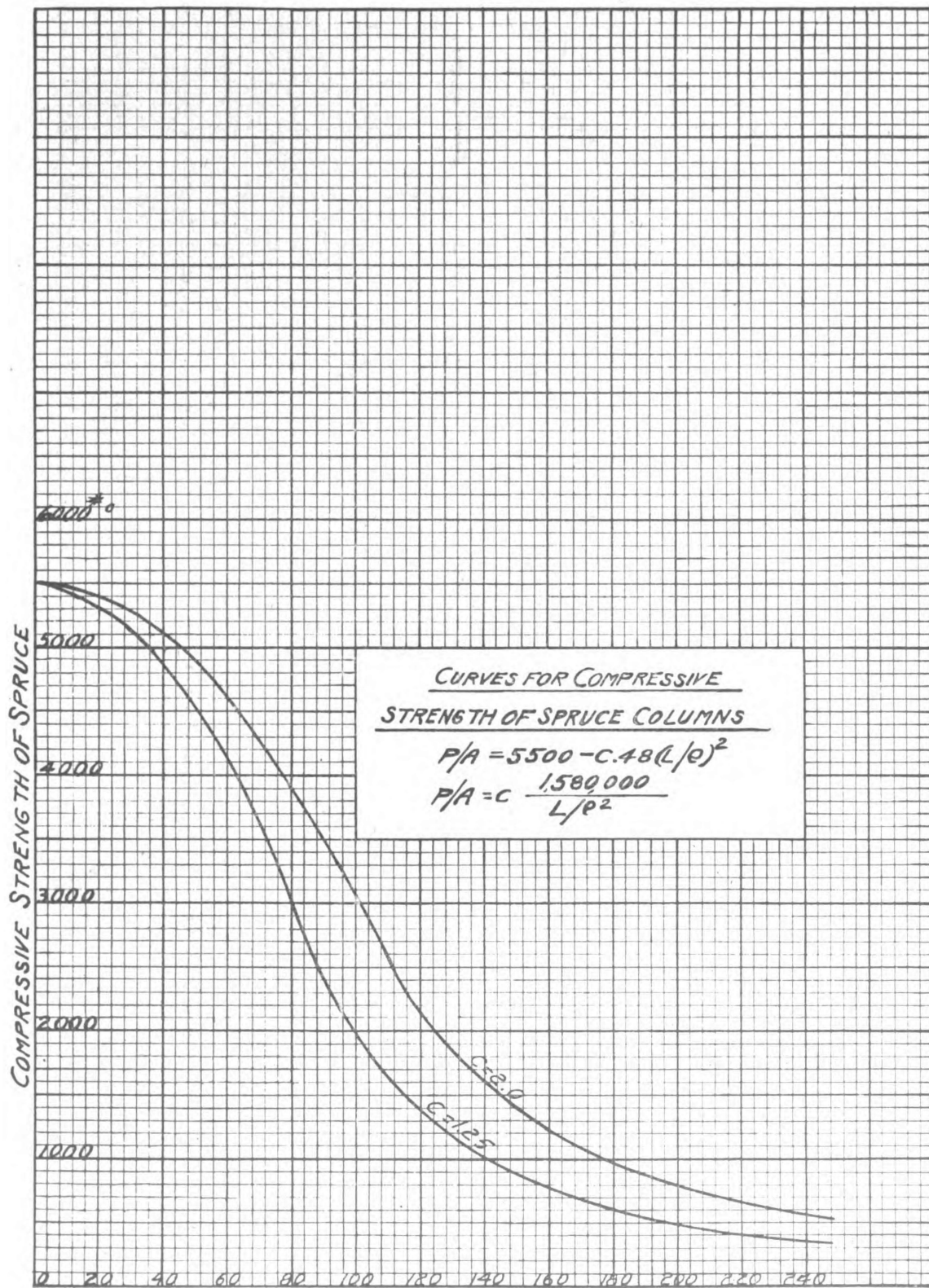


FIG. 4.

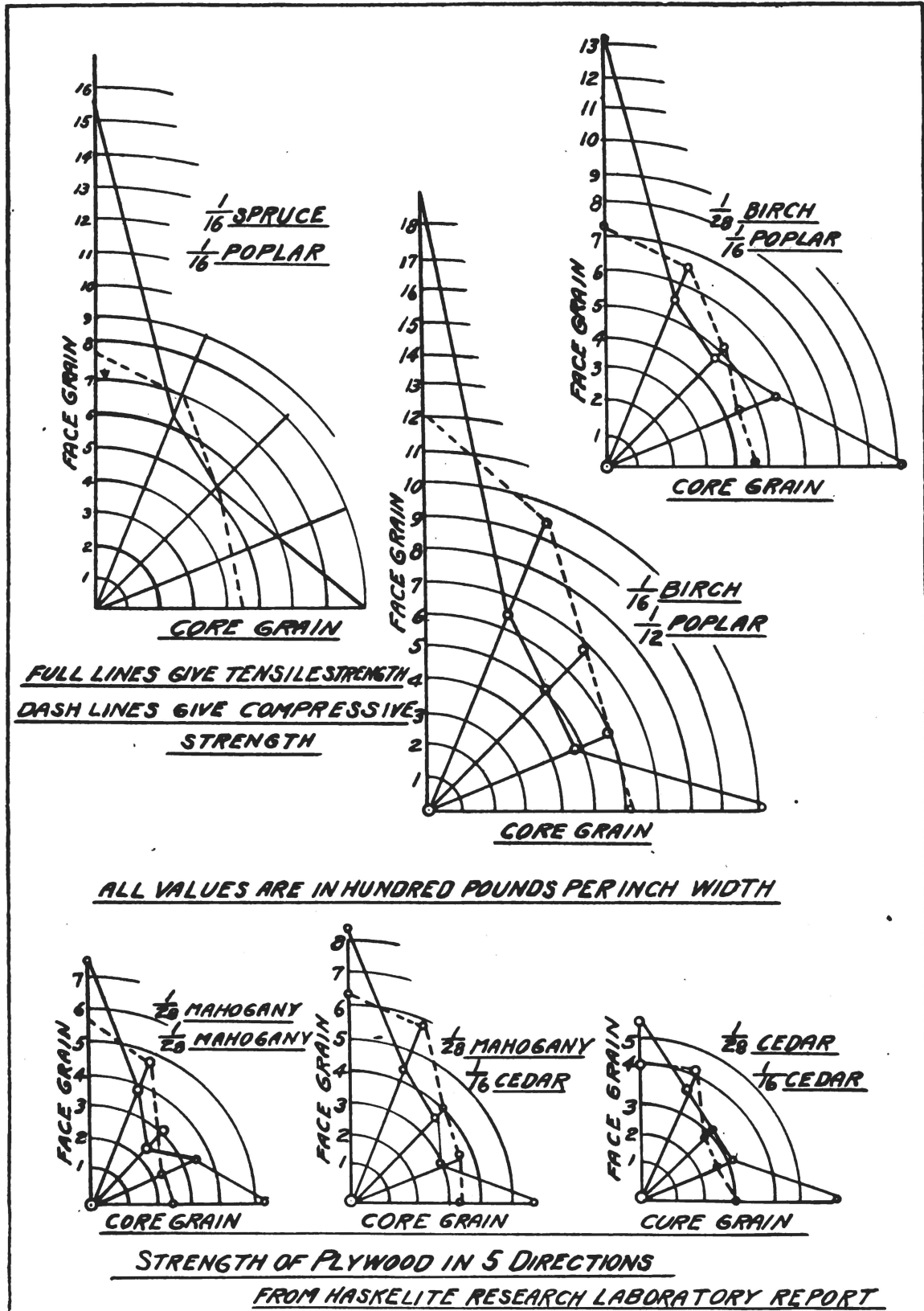


FIG. 5.

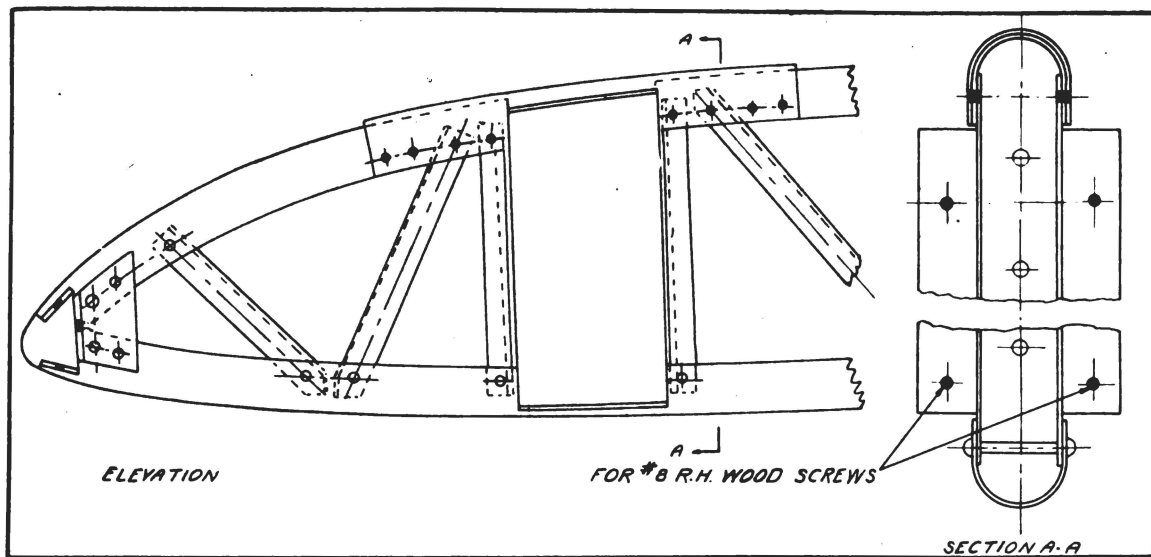


FIG. 6.—Attachment of duralumin rib to a wooden spar.

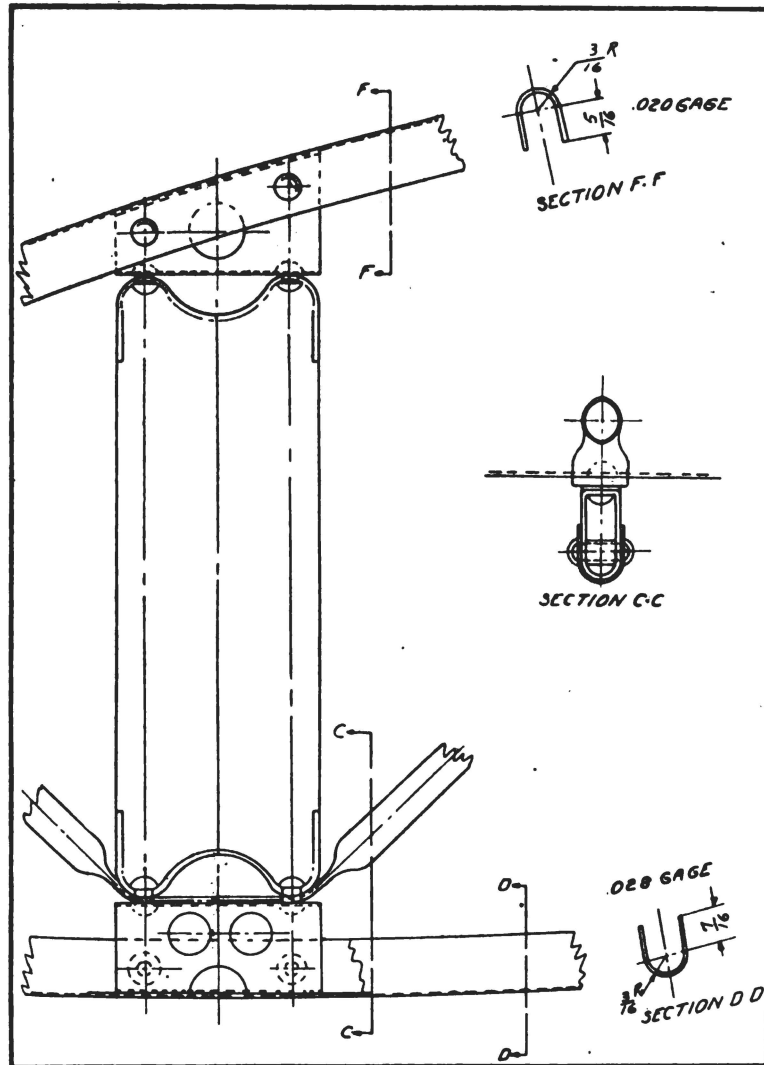


FIG. 7.—Connection of duralumin rib to duralumin spar.

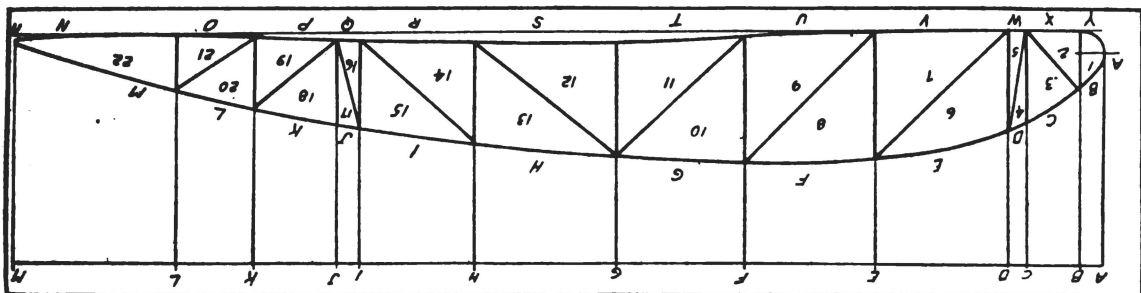


FIG. 8.—Key diagram for rib stresses to be used in conjunction with stress tables.

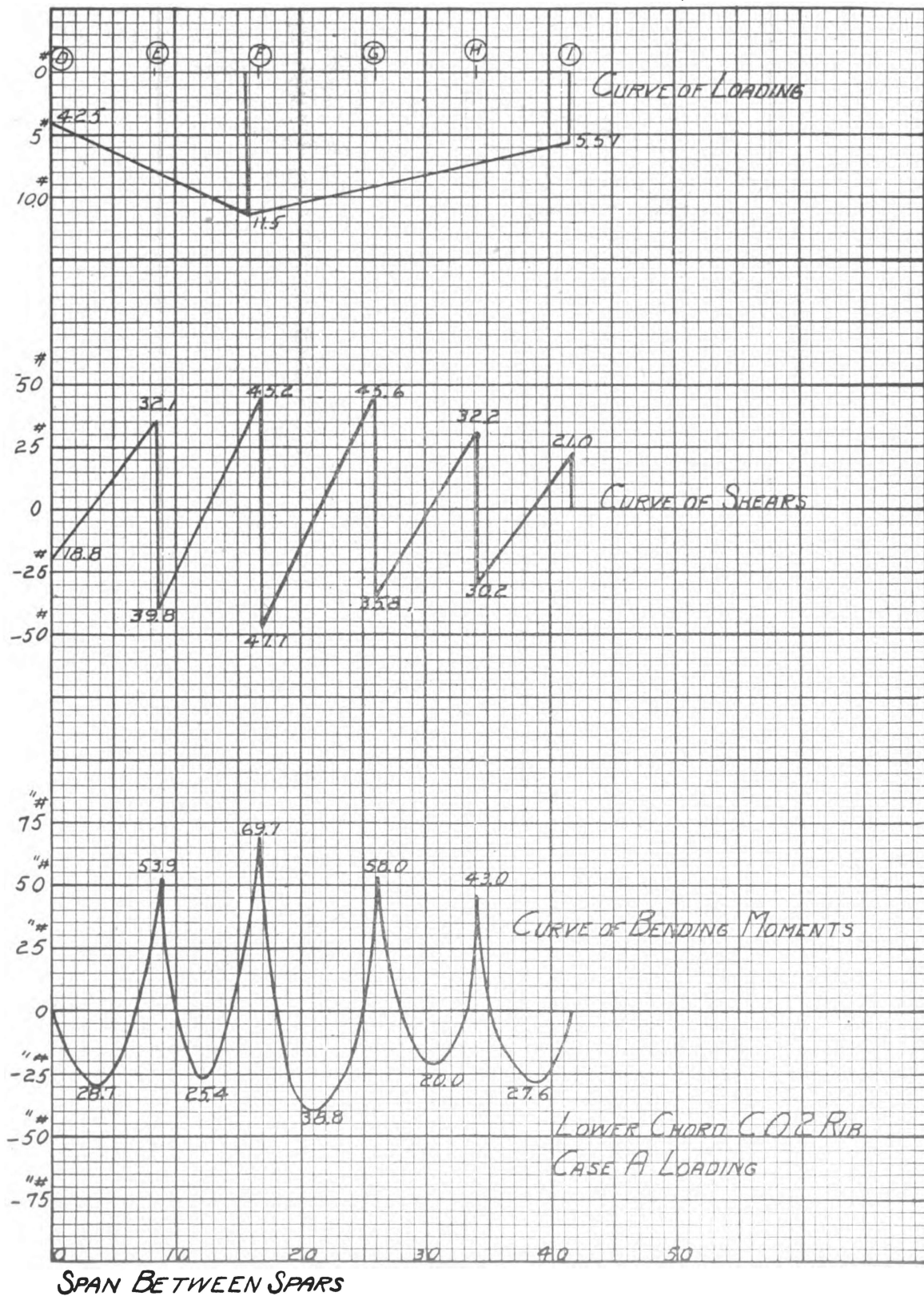


FIG. 9.

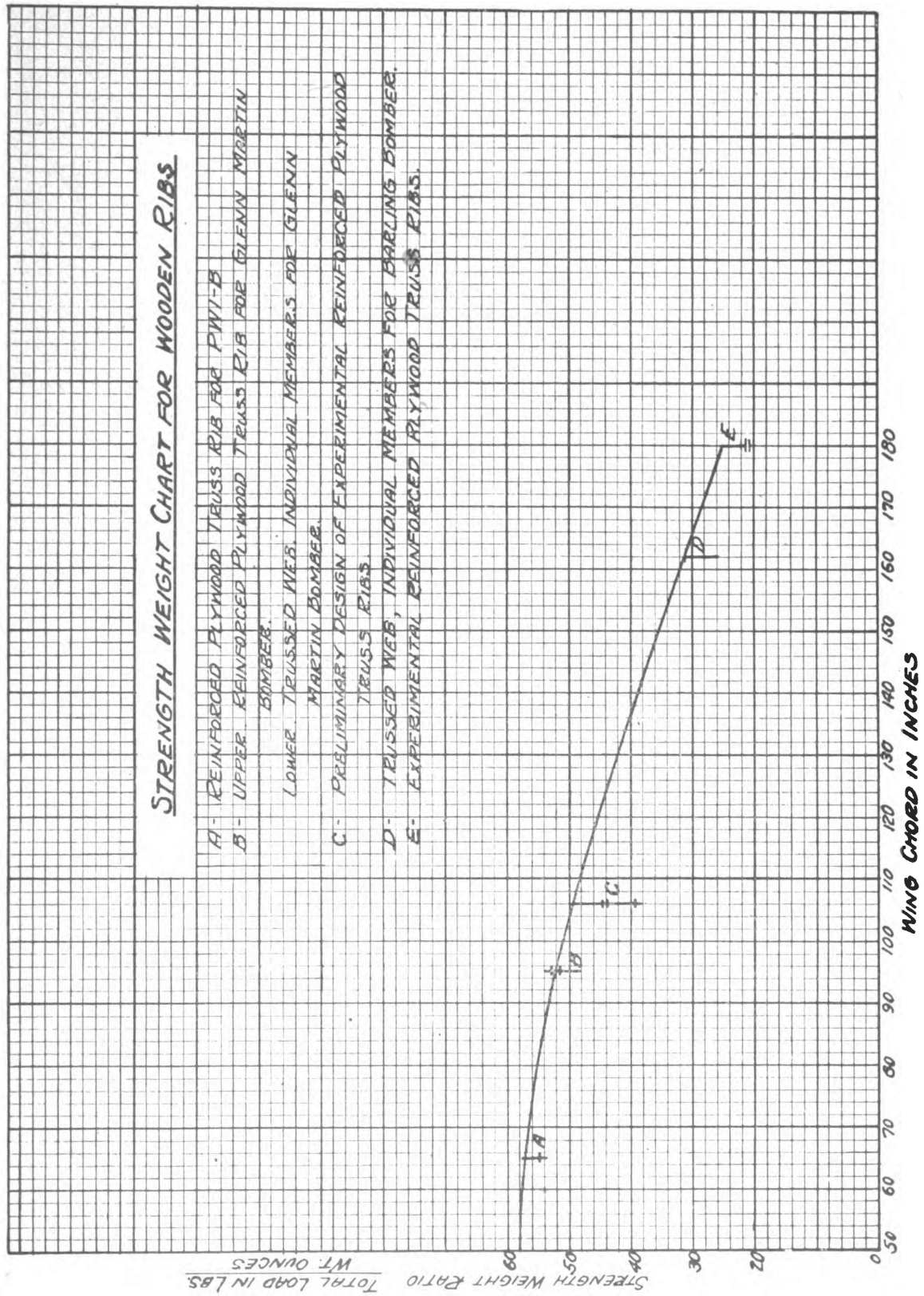


FIG. 10.